A Maximal Rowing Ergometer Protocol to Predict Maximal Oxygen Uptake in Female Rowers

Oscar B. Mazza[a], Søren Gam[a,b], Mikkel E. I. Kolind[a,b], Christian Kiær[a], Christina Donstrup[a], and Kurt Jensen[a*]

[a]Department of Sports Science and Clinical Biomechanics, University of Southern Denmark, Campusvej 55, 5230, Odense M, Denmark

[b] Department of Medicine, University hospital of Southern Denmark, Finsensgade 35, 6700, Esbjerg, Denmark

Please cite as: Mazza, O. B., Gam, S., Kolind, M. E. I., Kiær, C., Donstrup, C. & Jensen, K. (2023). A Maximal Rowing Ergometer Protocol to Predict Maximal Oxygen Uptake in Female Rowers. *SportRxiv*.

Corresponding author:

*Kurt Jensen, Department of Sports Science and Clinical Biomechanics, University of Southern Denmark, Campusvej 55, 5220, Odense M, Denmark

Tel. +45 65506089

Email: kjensen@health.sdu.dk

Abstract

Background: Laboratory assessment of maximal oxygen uptake ($\dot{V}O_2$max) is physically and mentally draining for the athlete and requires expensive laboratory equipment. Indirect measurement of $\dot{V}O_2$max could provide a practical alternative to laboratory testing. ***Purpose:*** To examine the relationship between the maximal power output (MPO) in an individualized 7x2 min incremental test (INCR-test) and $\dot{V}O_2$max and to develop a regression equation to predict $\dot{V}O_2$max from MPO in female rowers. ***Methods:*** 20 female club and Olympic rowers (development group) performed the INCR-test on a Concept2 rowing ergometer to determine $\dot{V}O_2$max and MPO. A linear regression analysis was used to develop a prediction of $\dot{V}O_2$max from MPO. Cross validation analysis of the prediction equation was performed using an independent sample of 10 female rowers (validation group). ***Results:*** A high correlation coefficient (r=0.94) was found between MPO and $\dot{V}O_2$max. The following prediction equation was developed: $\dot{V}O_2$max (mL·min^{-1}) = 9.58*MPO (W) + 958. No difference was found between the mean predicted $\dot{V}O_2$max in the INCR-test (3480 mL·min^{-1}) and the measured $\dot{V}O_2$max (3530 mL·min^{-1}). Standard error of estimate was 162 mL·min^{-1} and %SEE was 4.6%. The prediction model only including MPO, determined during the INCR-test, explained 89% of the variability in $\dot{V}O_2$max. ***Conclusion:*** The INCR-test is a practical and accessible alternative to laboratory testing of $\dot{V}O_2$max.

Keywords: indirect test; incremental test; maximal rowing performance test; $\dot{V}O_2$max; prediction equation

Introduction

Although many physiological and anthropometric parameters influence performance in Olympic rowing (2000 m), several studies have pointed towards maximal oxygen uptake ($\dot{V}O_2max$) as being the most important physiological predictor of 2000 m (2k) rowing performance.[1-4] Pripstein and colleagues suggested that aerobic metabolic processes were responsible for 88% of total energy production during a 2k ergometer race stimulation (2k-test) in female rowers.[5] Despite rowing competitions being faster nowadays, partly due to better equipment, the balance between anaerobic and aerobic work would still assumed be approximately the same. As men and females compete at the same distance (2k), females may, due to slower competition times, be even more dependent on aerobic capacity compared to anaerobic capacity.

Therefore, regularly monitoring of rowers $\dot{V}O_2max$ is important both in the selection process for rowing teams and in the evaluation of training plans to ensure optimal adaption.[6] Traditionally laboratory assessments of $\dot{V}O_2max$ have been measured during a maximal 6 min or 2k test performed on an air braked rowing ergometer.[3,7,8] The 2k-test on ergometer mimics performance during Olympic competitive rowing, where athletes row for 2000 m. Exercise time and physiological demands are similar and ergometer rowing requires approximately the same movement pattern as water rowing. The 2k-test has a high degree of reliability with a coefficient of variance (CV) for mean power of less than 2%.[7,8] This high degree of reliability makes it suitable for measuring specific rowing performance in national and international indoor championships and for team selection. However, the significant physiological and psychological stress from the 2k-test, makes it unsuitable for regular monitoring aerobic performance changes. Anecdotal evidence suggests that the test demands such a high level of exertion that it compromises motivation for completing the tes,t and negatively impacts subsequent training sessions. Therefore, an indirect and less demanding test that can be used frequently to estimate $\dot{V}O_2max$ within relative narrow limits would be desirable.

Several studies have suggested ways to indirectly assess $\dot{V}O_2max$ in rowers with varying degrees of success. Using a test consisting of submaximal rowing steps for 6 min at five different incremental speeds and their corresponding heart rate (HR), Lakomy and Lakomy were able to predict $\dot{V}O_2max$ with a mean error of estimate <5%.[9] Klusiewicz & Faff developed regression formulas based on HR data from a submaximal test and the $\dot{V}O_2max$ and average power output measured during a 2k-test.[10] These equations were able to estimate $\dot{V}O_2max$ with between 5.1 and 7.5% total error in female rowers.[10] However, sensitivity of the estimation was shown to be too low to detect changes in $\dot{V}O_2max$ during a training season.[10] Kendall et al. proposed the use of critical velocity and anaerobic rowing capacity to predict $\dot{V}O_2max$ in female collegiate rowers.[11] This method allowed for prediction of $\dot{V}O_2max$ with a standard error of estimate (SEE) of 4.6%.[11] This required the rowers to conduct four maximal efforts over a two-day period, which may be difficult to implement in regular training schedules. Huntsman et al. developed a maximal incremental test consisting of 7x2min steps with a 30 sec break.[12] $\dot{V}O_2$ and Peak HR achieved at the end of each step, were plotted in a linear regression model to predict $\dot{V}O_2max$. A moderate correlation (r=0.55) was found in the men, while no correlation was found for the women, suggesting the protocol was insufficient to reliably estimate $\dot{V}O_2max$ in female and male rowers.[12] In a recent study, Cherouveim et al 2022 found that maximal distance in the last step in a fixed 7 step incremental test and lean body mass, allowed for the estimation of $\dot{V}O_2max$ with a CV of 3.3 and 2.1% in male and female adolescents, respectively.[13] Recently, Jensen et al. proposed the use of a continuous incremental test (INCR-test) with self-selected drag factor and stroke rate to predict the $\dot{V}O_2max$ of male rowers.[14] The test used 7x2min steps with increasing intensity to exhaustion, where starting and subsequent workloads were individually adjusted based on each rowers estimated 2k performance.[14] In the study, 20 male rowers were used to develop the prediction equation and an independent sample of 14 male rowers were used for cross validation. The developed prediction equation was able to reliably estimate $\dot{V}O_2$max with a 3.1% error (136 $mL \cdot min^{-1}$) using only maximal power output (MPO) as predictor variable.[14]

We hypothesized that the same test protocol conducted by Jensen and colleagues would be able to predict $\dot{V}O_2$max in female rowers. It is therefore the aim of this study to develop an equation that can be used to estimate $\dot{V}O_2$max in female rowers using the same INCR-test method.

Methods

Participants

Thirty Danish female rowers (age 23.3 [2.84] years, height 1.74 [0.06] m, mass 70.0 [7.6] kg, fat free mass 49.8 [4.4] kg, rowing experience 5.2 [4.5] years), comprising 10 Olympic rowers and 20 club and university rowers, volunteered to participate in the study after providing written informed consent. Inclusion criterions were female rowers between 18 and 35 years with >6 months rowing experience and currently rowing ≥3 times per week (in boat or on ergometer). Participants were excluded if they had performed strenuous exercise <24 hours before testing, or if they were unwilling to pause administration of any ergogenic supplements (e.g., caffeine, creatine etc.) prior to testing. Participants consented to participate in the test protocols and were informed of all potential risks. The present study utilizes tests used during the ordinary training of the rowers. As such, the present protocol did not require ethical approval according to the local ethical committee (20212000-130).

Design

The participants performed the INCR-test on a Concept2 rowing ergometer (Concept2, Model D, Morrisville, VT, USA) until exhaustion. To develop and to test the validity of a prediction equation between MPO and $\dot{V}O_2$max, the participants were first balanced between Olympic and club rowers in two groups (with equal proportions of Olympic and club rowers) and then randomly assigned to a developmental group (n=20) and a validation group (n=10) (Table 1). MPO data from the developmental group were used to develop a prediction equation for estimating VO2 max.

Rowing ergometer tests

Before the INCR-test was performed, height was measured using a wall mounted height scale. Weight and fat free mass were measured using a scale with bioelectrical impedance analyzer (Tanita MC 780, Tanita Corp, Tokyo, Japan). The INCR-test was identical to the test used by Jensen and colleagues.[14] The rowers used self-selected stroke rate and drag factor during the test and warm-up protocol. The initial step and the load increase per step in the INCR-test were individually tailored to each rower's performance level as suggested by Jensen.[6] Following a brief (5 min) warmup, participants rowed continuously, without pause, with intensity gradually increasing every 2 minutes for 7± 1 steps or ~14 minutes. The starting step (step 1) equaled 40% of the participants average power output during a 2k-test (W_{2k}). For each subsequent step the participants had to increase their power output by 10% of their personal W_{2k}. Participants rowed continuously for as many steps as possible until exhaustion. The power output in final steps corresponding to 100 ± 10% of W2k. The test was stopped if the workload dropped by ≥10 Watts from the prescribed workload for > 4 consecutive strokes. The MPO during the INCR test was calculated as the average power at the last completed step plus 10% of their W_{2k} multiplied by the completed percentage of last initiated step. For example, if the participant had a W_{2k} of 300 and rowed for 13min (7 and a half step), their MPO would be 270 W + (50% of 30W) = 285 W. Test-retest reliability data were obtained for MPO during two INCR tests performed at the same weekday during two weeks of training in a group of 12 comparable female rowers. This resulted in an interclass correlation of 0.99, a technical error of measurement of 3.3W (or 1.5%) and a CV of 1.4%.

Determination of $\dot{V}O_2$max

Oxygen uptake was measured based on a dynamic mixing chamber system (AMIS Sport system; Innovision, Glamsbjerg, Denmark) for details see Jensen et al. 2021.[14] HR were recorded throughout the INCR-test using a HR monitor (Polar Sport Tester; Kempele, Finland). Rate of perceived exhaustion (RPE) was recorded immediately after each test using a Borg Scale (RPE 6-20). The highest mean 30-sec value for $\dot{V}O_2$ and Respiratory Exchange Rate (RER) during the INCR test was recorded as $\dot{V}O_2$max and RER_{max} respectively. To further ensure that the recorded value for $\dot{V}O_2$max represented a true maximum, 2 of the 3 following criteria had to be met before the value for $\dot{V}O_2$max was accepted for the INCR-test: (1) $RER_{max} > 1.10$; (2) RPE rating ≥ 17; (3)HR > 90% of the age predicted HR_{max} (Age predicted max= 220-age);

Statistical analyses

Data was analysed using Graph Pad Prism 7 software (Dotmatics, San Diego, USA). Data from the developmental group was fitted in a linear regression model, using $\dot{V}O_2$max as the dependent and MPO as the independent variable, to develop the $\dot{V}O_2$max prediction equation. A stepwise regression model that included both MPO and fat free mass was also developed. Internal cross validation analysis of the equation was conducted using the validation group. A parried T-test was conducted to see if there was a statistically significant difference between measured and predicted $\dot{V}O_2$max. SEE was calculated as the square root of 1/(n-2) multiplied by the sum of residuals squared. Relative SEE (%SEE) was calculated as SEE/measured $\dot{V}O_2$max multiplied by 100. A Bland-Altman plot was created to observe if systematic bias was present. Results with $p < 0.05$ were considered significant. All data are presented as mean (SD) unless otherwise stated.

Results

The developmental group had an exercise time to exhaustion during the INCR-test of 843 (57) s or 7.0 ± 0.4 steps.Fitting data from the developmental group in a linear regression model resulted in the following regression equation:

$$\dot{V}O_2\text{max (mL·min}^{-1}) = 9.58 * MPO + 958$$

A strong relationship between predicted and measured $\dot{V}O_2$max was observed using data from the validation group (r=.97, P<.0001) (Figure 1). Accordingly, the prediction model explained 89% of the variability in $\dot{V}O_2$max. Predicted $\dot{V}O_2$max was 3480 mL·min^{-1} whilst measured $\dot{V}O_2max$ was 3530 mL·min^{-1}. No significant differences were observed between predicted $\dot{V}O_2max$ and measured $\dot{V}O_2max$ (p=.2738). SEE was 162 mL·min^{-1} whilst %SEE was 4.6%. No drift in gas sensors measured before and after tests was observed in O_2, while a minor increase of 0.01% was seen for CO_2 ($p<.0001$, Table 2). Using a stepwise regression model that included both MPO and fat free mass was also developed. Adding fat free mass only improved the prediction equation minimally (r=0,98 P=0.33).

***Table 1 and 2 about here
***Figure 1 about here

Discussion

In this study, we used the previously developed INCR-test, which was individualized based on each participant W_{2k}. Using this protocol, participants could work at approximately the same gradually increasing relative intensity and reached exhaustion at approximately the same time.

No significant difference was found between measured $\dot{V}O_2max$ (3530 mL·min^{-1}) and estimated $\dot{V}O_2max$ (3480 mL·min^{-1}) using the developed prediction equation (P=.2738). The $\dot{V}$O2max was predicted with a SEE of 162 mL·min-1 and %SEE of 4.6%, indicating that VO2max obtained from the INCR test can accurately be predicted from MPO obtained from the same test.

In a recent study, Cherouveim et al 2022 measured performance during an incremental 7-step row test to predict the $\dot{V}O_2max$, of adolescent boys and girls between 13 and 17 years old from a national development team .[15] The authors were able to estimate $\dot{V}O_2max$ with a CV of 3.3 and 2.1% for males and females, respectively.[15] Unlike the present study, Cherouveim et al used a non-individualized test procedure with a fixed increase of work output each step, intermittent rest periods and gender-specific stroke rates. Cherouveim used body composition and test performance to predict $\dot{V}O_2max$.[15] Unlike Cherouveim, we did not see any benefit of adding any measure of body composition to the regression model, as adding this parameter only improved the prediction equation minimally (r=0,98 P=0.33 for lean mass). This may indicate that body composition is an important factor to consider when dealing with adolescents . Club level rowers rarely have access to valid measurements of body compositions and as such the inclusion of this would limit the practical application of the prediction equation.

Kendall et. al. showed that $\dot{V}O_2max$ could be predicted with a SEE of 144 mL·min^{-1} or 4.6% based on critical velocity and anaerobic rowing capacity in female college rowers.[11] This approach required four exhaustive tests over 2 separate days on a rowing ergometer (400, 600, 800 and 1000 m).[11] In comparison, the INCR-test is much less time consuming (~14 minutes) and induces less physical stress on the rowers. Both Kendals et al.'s prediction equation and the one developed in the present study have the same %SEE of 4.6%.

In another study, using the INCR-test, Jensen showed that the $\dot{V}O_2max$ of male rowers could be estimated using a 2k-test with almost the same level of accuracy as the INCR-test.[14] However, compared to the 2k-test, the INCR-test induced lower post-test blood lactate values and less fatigue, indicating that the INCR-test would be more convenient for regular application than the 2k-test.[14] Importantly, no statistically significant difference was observed between $\dot{V}O_2max$ measured in the INCR-test vs the 2k-test.[14] Applying the prediction equation for the male rowers to the female validation group from the present study, resulted in a significant difference between predicted and measured $\dot{V}O_2max$ values (p=<0.0001). This highlights the need for gender specific prediction equations.

Changes in ambient conditions in the laboratory room during the exercise could potentially influence results.[16-18] In this study all tests were performed in well ventilated rooms to

secure stable ambient conditions. Electronic drift in the equipment could also lead to measurement error.[16] In this study, a small but statistically significant increase was observed in CO_2 but not in O_2 from pre- to post-test gas check (Table 2). In a few individual cases, where a drift in O_2 larger than 0.05% was observed, the results were recalculated using the observed drift as reference. Accordingly, in this study, the highest potential individual $\dot{V}O_2max$ measurement error, due to gas drift in O2 concentration would be less than 0.8%.
Several of the participants had no prior experience with the INCR-test. However, all were accustomed to the Concept II row ergometer, and all received thorough verbal instructions and got experience with the initial two levels of the INCR-test during warm-up. Test-retest variation in had a CV of 1.4% in a comparable group of 12 female rowers, which was slightly lower that the repeatability for male rowers.[14]. Future research is needed to determine the responsiveness of the INCR-test to changes in $\dot{V}O_2max$ during different periods over a rowing season. Our hypothesis would be that the sensibility of the equation will decrease when changing training towards larger portions of anaerobic training. We suggest testing MPO (by INCR-test) and measuring $\dot{V}O_2max$ before and after a training phase. Changes of each parameter could then be compared to determine responsiveness.

Practical Applications

Compared to other available row performance test to estimate $\dot{V}O_2max$ the INCR-test may be more suited for testing the aerobic capacity of inexperienced or frail athletes since the tests is based on individual performance. While the test requires an initial estimate of 2k-test performance this is easily sidestepped in practice by giving a best estimate and having the athlete row until exhaustion (as defined in present protocol). After which, the last achieved step is used for future reference. Using this method, a single trial is, in our experience, sufficient to design a progression schedule with participants reaching exhaustion at approximately step 7.
For regular monitoring of training status in female rowers, we suggest using the INCR-test, as this test allows for athletes to be tested with approximately the same exercise time to exhaustion, the same relative starting level and same relative intensity increment increase per step. From the obtained MPO in the test, the $\dot{V}O_2max$ can be estimated with an accuracy of ± 4.6%.

Conclusions

We have shown that MPO in the INCR-test can be used to accurately predict $\dot{V}O_2max$ in female club and elite rowers. Additional studies over longer periods of training are required to test the responsiveness and accuracy of the $\dot{V}O_2max$ predicted from MPO

Acknowledgements

The author thanks the rowers and coaches for their participation in this study. There are no conflicts of interest. There are no companies or manufacturers who will benefit from the results of this study.

References

1. Bourdin M, Lacour JR, Imbert C, Messonnier LA. Factors of Rowing Ergometer Performance in High-Level Female Rowers. *Int J Sports Med.* 2017;38(13):1023-1028.

2. Cosgrove MJ, Wilson J, Watt D, Grant SF. The relationship between selected physiological variables of rowers and rowing performance as determined by a 2000 m ergometer test. *J Sports Sci.* 1999;17(11):845-852.
3. Ingham SA, Whyte GP, Jones K, Nevill AM. Determinants of 2,000 m rowing ergometer performance in elite rowers. *Eur J Appl Physiol.* 2002;88(3):243-246.
4. Nevill AM, Allen SV, Ingham SA. Modelling the determinants of 2000 m rowing ergometer performance: a proportional, curvilinear allometric approach. *Scand J Med Sci Sports.* 2011;21(1):73-78.
5. Pripstein LP, Rhodes EC, McKenzie DC, Coutts KD. Aerobic and anaerobic energy during a 2-km race simulation in female rowers. *Eur J Appl Physiol Occup Physiol.* 1999;79(6):491-494.
6. Jensen K. Performance Assessment In: Secher NH, Volianitis S, eds. *Rowing* Blackwell Publishing 2007:96-102.
7. Schabort EJ, Hawley JA, Hopkins WG, Blum H. High reliability of performance of well-trained rowers on a rowing ergometer. *J Sports Sci.* 1999;17(8):627-632.
8. Smith TB, Hopkins WG. Measures of rowing performance. *Sports Med.* 2012;42(4):343-358.
9. Lakomy HK, Lakomy J. Estimation of maximum oxygen uptake from submaximal exercise on a Concept II rowing ergometer. *J Sports Sci.* 1993;11(3):227-232.
10. Klusiewicz A, Borkowski L, Sitkowski D, Burkhard-Jagodzińska K, Szczepańska B, Ładyga M. Indirect Methods of Assessing Maximal Oxygen Uptake in Rowers: Practical Implications for Evaluating Physical Fitness in a Training Cycle. *J Hum Kinet.* 2016;50:187-194.
11. Kendall KL, Fukuda DH, Smith AE, Cramer JT, Stout JR. Predicting maximal aerobic capacity (VO2max) from the critical velocity test in female collegiate rowers. *J Strength Cond Res.* 2012;26(3):733-738.
12. Huntsman HD, DiPietro L, Drury DG, Miller TA. Development of a rowing-specific VO2max field test. *J Strength Cond Res.* 2011;25(6):1774-1779.
13. Almquist NW, Nygaard H, Vegge G, Hammarström D, Ellefsen S, Rønnestad BR. Systemic and muscular responses to effort-matched short intervals and long intervals in elite cyclists. *Scand J Med Sci Sports.* 2020;30(7):1140-1150.
14. Jensen K, Frydkjær M, Jensen NMB, Bannerholt LM, Gam S. A Maximal Rowing Ergometer Protocol to Predict Maximal Oxygen Uptake. *Int J Sports Physiol Perform.* 2021;16(3):382-386.
15. Cherouveim E, Methenitis S, Simeonidis T, et al. Validity and Reliability of New Equations for the Prediction of Maximal Oxygen Uptake in Male and Female Elite Adolescent Rowers. *Journal of Human Kinetics.* 2022;83:77-86.
16. Gore CJ, Tanner RK, Fuller KL, Stanef T. Determination of Maximal Oxygen Consumption (VO2max) In: Gore CJ, Tanner RK, eds. *Physiological Tests for Elite Athletes Second Edition* Second Edition ed.: Australian Institute of Sport 2013:103-122.
17. Macfarlane DJ. Automated metabolic gas analysis systems: a review. *Sports Med.* 2001;31(12):841-861.
18. Shephard R. Open-circuit respirometry: a brief historical review of the use of Douglas bags and chemical analyzers. *Eur J Appl Physiol.* 2017;117:1-7.

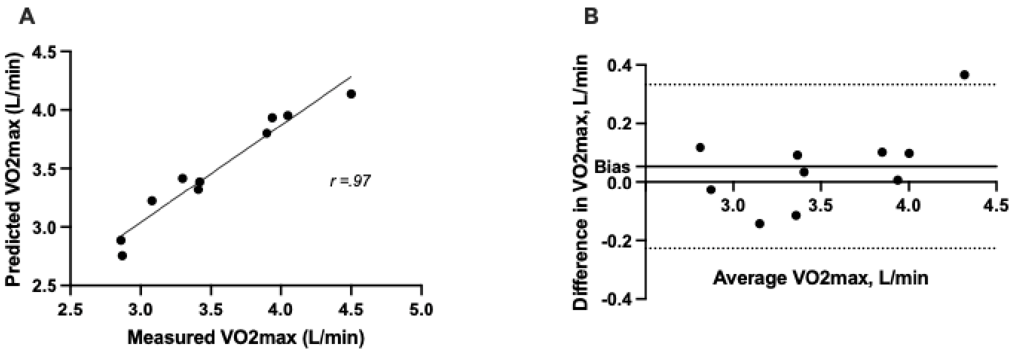

Figure 1 *- Linear relationship (A) and limits of agreement (B) between observed V̇O2max and the predicted V̇O2max using INCR test. Bias-lines represent the mean difference between observed and predicted V̇O2max values. Dashed lines represent the 95% limits of agreement.*

Table 1: Physiological Characteristics for Development and Validation group (Mean (SD))

	Development Group n=20	Validation Group n=10
Age (y)	23.3 (3.35)	23.3 (1.49)
Height (m)	1.74 (0.06)	1.74 (0.05)
Weight (kg)	69.9 (7.65)	70.2 (7.99)
Experience (y)	5.2 (4.44)	5.2 (4.72)
$\dot{V}O_2max$ (L/min)	3.4 (0.56)	3.5 (0.60)

Characteristics of both the development and validation group

Table 2: Drift in O_2 and CO_2 sensors before and after tests (Mean (SD))

	Pretest, Mean (SD)	Posttest, Mean (SD)	Difference (P)
Sensor O2, %	15.36 (0.52)	15.37 (0.51)	0.01 (0.587)
Sensor CO2, %	4.78 (0.55)	4.79 (0.55)	0.01 (0.0001)

Pre- and post-test values for sensor O2 – and CO2. No significant difference was found in O2, whilst a small statistically significant difference was found in CO2